Climate Risk Mapping in the Philippines for Sub-National Targeting and Prioritization for Crop Diversification to Increase Resilience of the Agricultural Sector

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Abstract

The Philippines is among the top most vulnerable country to climate change and is considered to have the highest sensitivity to extreme weather events as compared to other Asian countries. Agriculture is one of the most affected sectors to climate change, especially to extreme weather events causing significant economic loss. The agenda for climate change adaptation during recent decades has developed the concept of vulnerability to better understand the potential impacts of climate change on livelihoods and agricultural production, and identify the necessary package of interventions needed to ensure food security under progressing climate change. There has been several innovative researches and approaches on vulnerability and risk assessments to help governments and other sectors to target and guide adaptation strategies based on main climate risks and socio-economic conditions with various vulnerability and risk assessments done in the Philippines.

This study aimed to map "municipality-level" coverage of all high risk zones in the Philippines in high resolution using a compilation of official hazard and available socio-economic dataset to support climate change adaptation through agricultural diversification. The approach focused on assessing the risk of climate-related impacts (hazards) that may negatively affect agricultural communities. Thus, high-risk zones to climate change, variability and extremes was assessed and mapped in all municipalities in the Philippines using spatial modeling and statistical analysis of climate hazards and poverty incidence. The analyses focused on key climate risk that threatens the productivity of agricultural commodities in the Philippines at the municipal resolution where significant decision making and planning takes place, especially in the agricultural sector. The municipality-level hazard risk and susceptibility maps for typhoon, flood, drought, sea level rise, and salt water intrusion showed the effect to agricultural production, particularly rice and maize which are exposed to the impact of typhoon and farmers are at a high risk in terms of crop losses. The high risk zones (integration of climate risk and poverty incidence) in the Philippines are geographically distributed in the northeastern part (Region 2 and portion of Cordillera Autonomous Region), eastern seaboards (Regions 5 and 8), and central to western part of

Mindanao (Regions 9, 10, ARMM, and 12). Based on the cluster analysis of high-risk zones, the author suggested three cluster for practical uses for planning climate change adaptation, which included (1) cluster 1 for agricultural systems should focus on drought resilience, (2) cluster 2 for agricultural systems should focus on addressing the typhoon risk, and (3) cluster 3 for agricultural intervention should focus on provision for drought resilience cropping system. More importantly, the relevance of root tuber and banana in high-risk zones were mapped and this shows the climatic suitability of sweet potato, cassava, and potato in the high risk zones. Sweet potato and cassava remains highly suitable by year 2050; while potato is simulated to decrease in climatic suitability and will likely recede to higher altitudes due to warmer temperature. Aside from its resilience to climate change, sweet potato and cassava are known to tolerate drought and these crops can also endure typhoons as compared to rice and maize.

The study on mapping of high risk zones is very useful to inform and guide decision makers from government agencies and private sectors on geographic areas that are in most need of interventions, and the package of interventions needed for each geographical area. The study will directly contribute to the on-going initiative of the Philippine government to reduce climate risk and improve livelihoods of the agricultural sector thru the provision of climate smart agriculture.

Keywords

High Risk Zones, Climate Change, Root and Tuber Crops, Philippines

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Acronyms

ARMM	Autonomous Region of Muslim Mindana0
CIAT	International Center for Tropical Agriculture
CRVA	Climate Risk Vulnerability Assessment
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CGIAR	Consortium of International Agriculture Research
CIP	International Potato Center
DA	Department of Agriculture
ENSO	El Niño Southern Oscillation
FOODSTART+	Food Resilience Through Root and Tuber Crops in Upland and Coastal Communities of the Asia-Pacific
IPCC	Intergovernmental Panel on Climate Change
OML	Oscar M. Lopez Center
(PAGASA)	Philippine Atmospheric Geophysical Astronomical Services Administration
PCA	Principal Component Analysis
PSA	Philippine Statistics Authority
RTC	Root and Tuber Crops
UNDP	United Nations Development Programme

Introduction

The Philippines has been classified as the 3rd most vulnerable country to climate change across 67 countries and is considered to have the highest sensitivity to extreme weather events as compared to other Asian countries (Paun et al. 2018). Climate change can alter hydrologic regimes that can exacerbate occurrence and intensity of hazards and other extreme weather events. According to Cruz et al (2007), the frequency and intensity of tropical cyclones originating in the Pacific has increased over the last few decades. Based on the report of OML (2017), typhoons Reming, Loleng, and Yolanda (international names – Durian, Babs, and Haiyan) were the highest maximum gustiness ever recorded (OML 2017). Moreover, the Emergency Events Database (EM-DAT: http://www.emdat.de) shows that globally there is a steady increase of tropical cyclone occurrences from the 1900s with a notably higher number of occurrences after 1990s (although highly variable) (Figure 1). It is known that agriculture is one of the most affected sectors to climate change (Field et al. 2014), especially to extreme weather events. In fact, the United Nations Development Programme (UNDP) indicated that climate related disasters are becoming more devastating for the agricultural sector, such that during 2006-2013, the economic loss for the agricultural sector was estimated at USD3.8 billion caused by extreme weather events (UNDP 2019).

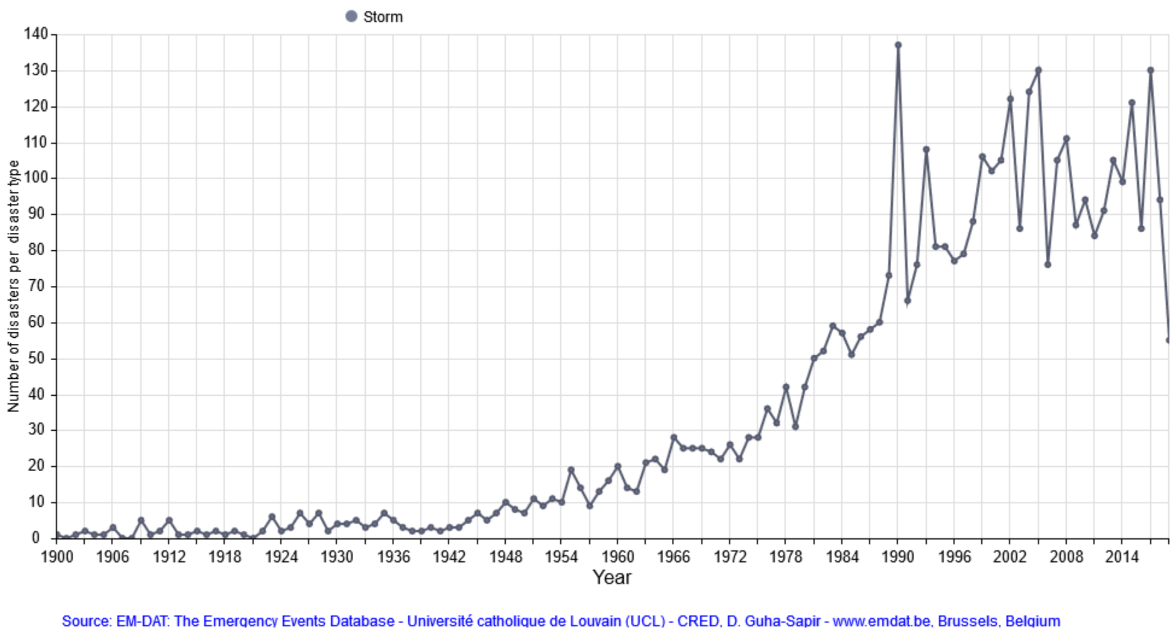

Figure 1: Number of typhoons reported globally from 1900 to 2020 from CRED EM-DAT database (https://www.emdat.be)

The agenda for climate change adaptation during recent decades has developed the concept of vulnerability to better understand the potential impacts of climate change on livelihoods and agricultural production, and identify the necessary package of interventions needed to ensure food security under progressing climate change. This has led to intensive, extensive and innovative researches on vulnerability and risk assessments to help governments and other sectors to target and guide adaptation strategies based on main climate risks and socio-economic conditions. In 2012, the IPCC has moved from a vulnerability to a risk-based approach to support climate change adaptation (Connell et al. 2018). The new framework introduces a new approach and terminology that moves closer to disaster risk concept. However, under data scarce region, this new approach could be difficult to implement. Nevertheless, national-, subnational-, and local-level assessments based on sound scientific basis should be done to support government agencies in charge of strategic decision making and planning processes to ensure that a more inclusive growth to agriculture that supports climate change adaptation are in place. Several vulnerability and risk assessments have been done in the Philippines. The characteristics of most of the VAs and risk assessments are: coarse spatial resolution, un-scalable methodology, sparse coverage, attributed to one single extreme event rather than looking at trends or patterns, and limited use of climate projections coupled with ecological models to assess impacts (Palao et al. 2019). The objective of this study is to map "municipality-level" coverage of all high risk zones in the Philippines in high resolution using a compilation of official hazard and available socio-economic dataset to support climate change adaptation through agricultural diversification. The "municipality-level" is the suggested scale of the analysis since most of agricultural planning and implementation of various programs and projects from the government and private sectors are implemented at this scale. Hence, it is pragmatic to target the municipalities at high risk zones. The approach focuses on assessing the risk of climate-related impacts (hazards) that may negatively affect agricultural communities which is a "component" of the risk concept suggested by the Intergovernmental Panel on Climate Change Assessment Repot 5 (IPCC 2014). It accounts for the fact that a large proportion of inter-related impacts are triggered by hazardous events. The hazard in this context is defined as the nature and degree to which a system is exposed to significant climatic variations and extreme events (Parker et al. 2019).

Methodology

Figure 2 describes the data requirements, information flow and processes for the assessment. The analysis estimates the geographic areas that are at high risks to climate change. Different spatial datasets have been prepared for this analysis and was applied to the Philippines, a major agricultural region in Southeast Asia.

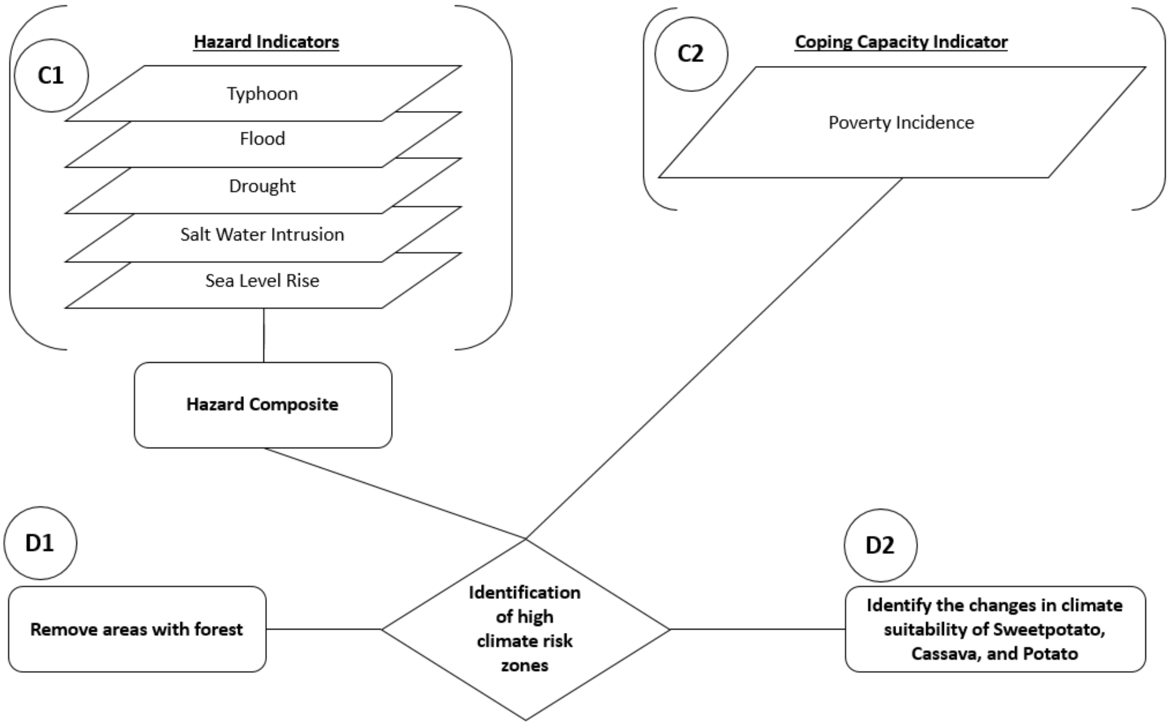

Figure 2: Framework composed of 4 processes to identify high-risk zones in the Philippines, and the relevance of RTB under progressing climate change

Process C1. The hazard datasets refers to historical databases to evaluate the current susceptibility of a hazard to occur in a geographic area. In this case, we define the resolution of a geographic area to a municipality. We limit the analysis of hazards to baseline conditions and trends because many climate hazards can be large scale singular events and projections to future conditions can introduce high level of uncertainty in the analysis. The succeeding section below discusses the procedure in developing the hazard composite.

Table 1 shows the data sources that were used to develop the hazard composite. Spatial overlay of climate-related natural hazards was used to determine the high hazard zones in the

Philippines. Hazards are identified based on its known potential impact on the agricultural sector and it is characterized by their extent, magnitude, severity, duration and variability. Therefore, weights – based on a consultative process – should be assigned before combining the hazard data to form the hazard composite. The weights for each hazard will be adopted from the climate risk vulnerability assessment (CRVA) study of CIAT[1] (Palao et al. 2019) based on consultation with local and national experts – typhoon (18%), flood (17%), drought (15.7%), salt water intrusion (9.6%), and sea level rise (6.3%). In the Philippines, higher weights are usually assigned to typhoon, flood and drought. Historically, these are the climate pressures that cause significant production losses which negatively affect food security and livelihoods. Table 2 shows the aggregated impacts of natural hazards in the Philippines. Typhoon has the highest occurrence (359 events) which results to considerable economic damage of USD21.9 billion as compared to flood and drought with a total economic damage of USD3.8 billion and USD148 million. The economic damage of these three major hazards were consistent with the weights used in this study, where typhoon has the highest weights, followed by flood and drought.

Table 1: Overview of hazard dataset that will be used to assess the exposure component

Parameter	Source	Unit of measurement, spatial and temporal resolution
Typhoon	UNEP / UNISDR, 2013 (https://preview.grid.unep.ch/)	1 kilometer pixel resolution. Estimate of tropical cyclone frequency based on Saffir-Simpson scale category 5 (> 252 km/hr) from year 1970 to 2013.
Flooding	Mines and Geosciences Bureau, Department of Environment and Natural Resources (MGB, DENR)	1:10,000 scale. Susceptibility of flood risk for Philippines from the past 10 years
Sea Level Rise	AMIA multi-hazard map	Assumption based on 5m sea level rise
Salt Water Intrusion	National Water Resources Board (NWRB)	Groundwater potential of the Philippines
Drought	TerraClimate (University of Idaho)	≈4 kilometer pixel resolution. Estimate based on Palmer Drought Severity Index (PDSI) from 1958 to 2017

[1] International Center for Tropical Agriculture

Most of the hazard data were gathered from secondary sources except for drought. The drought dataset was derived by analyzing global monthly Palmer Drought Severity Index (PDSI) from 1958 to 2017 provided by TerraClimate (https://climatedataguide.ucar.edu) from the University of Idaho (Abatzoglou, et al. 2018). Pixels were flagged as drought if the value is less than or equal to -2.0 (moderate to severe drought). The number of times a pixel was classified as drought and the number of years of analysis was used to determine the drought incidence in terms of percentage (%). The monthly incidence was aggregated to derive the historical drought incidence layer in the Philippines.

Table 2: Summary of natural disasters recorded by the EM-DAT database (https://www.emdat.be) in the Philippines

Disaster type	Events count	Total affected	Total damage ('000 US$)
Typhoon[2]	359	176,271,922	22,167,041
Flood[3]	151	33,555,034	3,811,363
Drought	10	6,750,894	148,852

The aggregation of each hazard and subsequent overlay analysis to derive the hazard index is shown in Figure 3. To compute for hazard composite, each pixel of a hazard layer was aggregated (average or sum) at the municipality level. The aggregated value of each hazard per municipality was normalized using $\frac{X - X_{min}}{X_{max} - X_{min}}$ (where X is an instance of the dataset, and X_{min} and X_{max} is the minimum and maximum value in the dataset) and was used as a proxy value to determine high hazard zones based on high and low values of the normalized dataset.

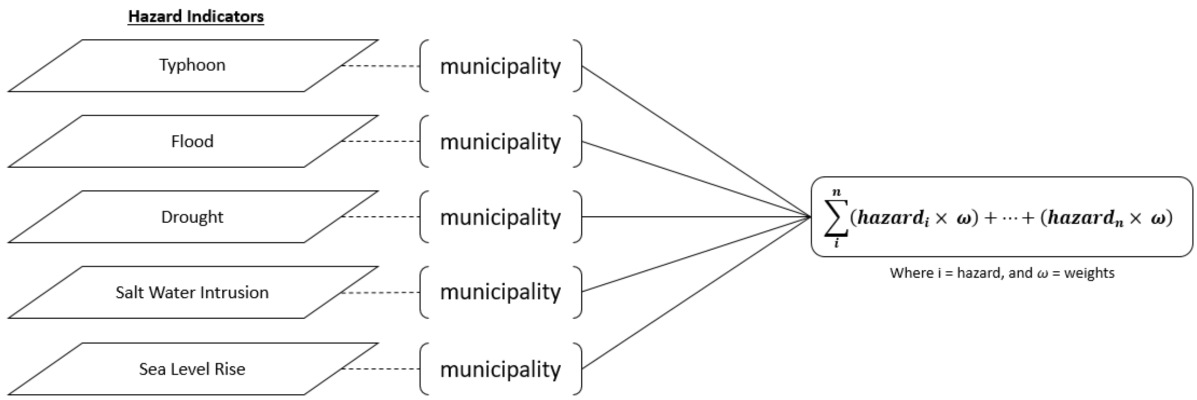

Figure 3: Schematic diagram of overlay analysis to combine spatial dataset for exposure.

[2] Convective and tropical cyclone classification

[3] Coastal flood, flash flood, and riverine flood classification

Process C2. Poverty incidence was assumed as a proxy indicator for coping capacity. This indicator assumes that in municipalities with higher poverty incidence, the coping capacity of the communities is low, that they are at high risk to hazards which is an extreme climate event. The Philippine Statistics Authority (PSA) published the poverty incidence by municipality using small area estimates (SAE) for year 2015 for the whole Philippines. The data was mapped using the HDX municipal administrative boundary dataset (ADM3_PCODE). Normalized hazard composite and poverty incidence were combined (hazard + poverty incidence) using equal weights to derive the municipalities at high risk zones in the Philippines.

Dataset D1. To retain only the areas that are available for agricultural use, the forest cover was used to remove areas that should not be used for agriculture.

Dataset D2. The FoodSTART+ (2019) (https://hdl.handle.net/10568/103731) provides the input for climate scenarios based on the climate change suitability mapping in Asia using crop distribution model, with a special focus on root and tuber crops (RTC). The scenario for year 2050 using RCP 8.5 was used to assess relevance of RTB in high risk zones, specifically to determine if RTB remains suitable under progressing climate change after 30 years.

Cluster Analysis to Characterize High Risk Zones. Cluster analysis was applied to reveal patterns in the "high-risk zones" that have similar characteristics in terms of climate hazards and poverty incidence. Principal Component Analysis (PCA) (Husson et al., 2018) was used to reduce the dimension of the dataset by searching the dimensions that explains the most variance in the data. We used first five principal components which accounts for ≈70% of the cumulative variance in our data. The Euclidean with 1000 iterations was used to parameterize K-means clustering algorithm to cluster the dataset. We identified three clusters with substantial difference in climate risk and poverty incidence ranking.

Results and Discussion

Climate Hazards

The municipalities at risk for each climate hazard in the Philippines, such as typhoon, flood, drought, salt water intrusion, and sea level rise is shown in Figure 4. Based on the NOAA (2015) report, the Philippines is considered the second most exposed country in the world to typhoons, receiving at least 15 typhoons (aggregate of tropical storms and typhoons) a year

(PSA, 2014). Northern Luzon, Southeastern Luzon, and Eastern Visayas are the geographical regions with high incidence of typhoons and tropical storms. This extreme weather hazard can cause billions of pesos in terms of damage to agriculture. In 2015, Typhoon Lando had caused extensive damage to agriculture amounting to almost Php5.9 billion. Among the affected provinces, Nueva Ecija suffered the most damage to agriculture with an estimate amount of Php3.5 billion (Rappler, 2015. Data source from Department of Agriculture).

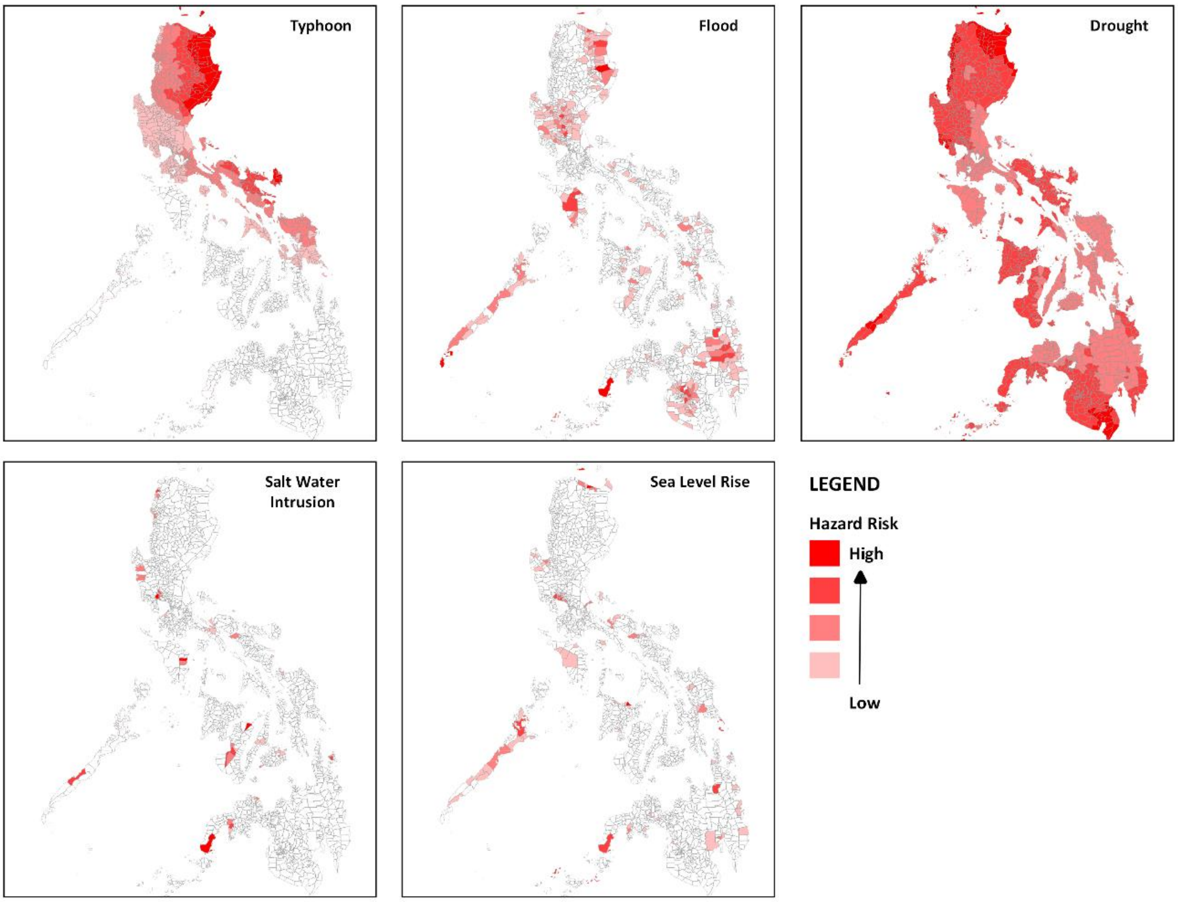

Figure 4: Municipality-level hazard risk and susceptibility maps for typhoon, flood, drought, sea level rise, and salt water intrusion.

Agricultural production in the Philippines, particularly rice and maize, are exposed to the impact of typhoon and farmers are at a high risk in terms of crop losses. The rice growing season, which typically ranges from June to October (based on peak of planting) also coincide with high incidence of typhoons (Figure 5). The economic vulnerability of the agricultural sector to typhoons being the most damaging geophysical hazard was highlighted by FAO (2015) in their recent disaster analysis for the Philippines: *"Most of the production damage and losses [are] caused by typhoons/storms, amounting to USD 3.5 billion or 93 percent [for* *the agricultural sector]. The majority of the damage and losses in the agriculture sector were in the crop subsector with USD 3.1 billion [for the period 2006-2013]".*

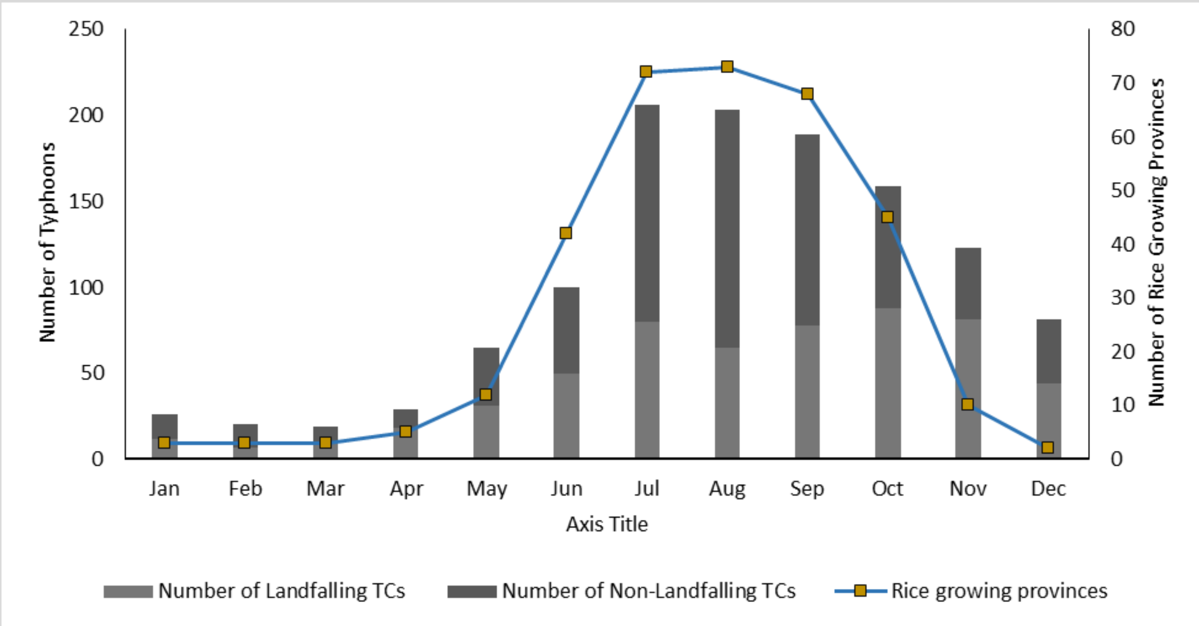

Figure 5: Temporal risk of typhoon in the Philippines showing A) monthly frequency of tropical cyclones entering the Philippine Area of Responsibility (PAR) from 1951-2013 (Cinco, et al. 2016) and estimated rice growing provinces in the Philippines (Laborte, et al. 2017).

Globally, flood events show an increasing trend from 1900s to 2020 (Figure 6). Flood is the second most damaging hazard as compared to drought. Although drought can cause widespread devastation and has a longer duration, its occurrence is much less compared to flood. In the Philippines, the aggregated economic damage of flood amounts to USD3.8 billion. Climate change and loss in forest cover will likely exacerbate the occurrence of flooding in the Philippines.

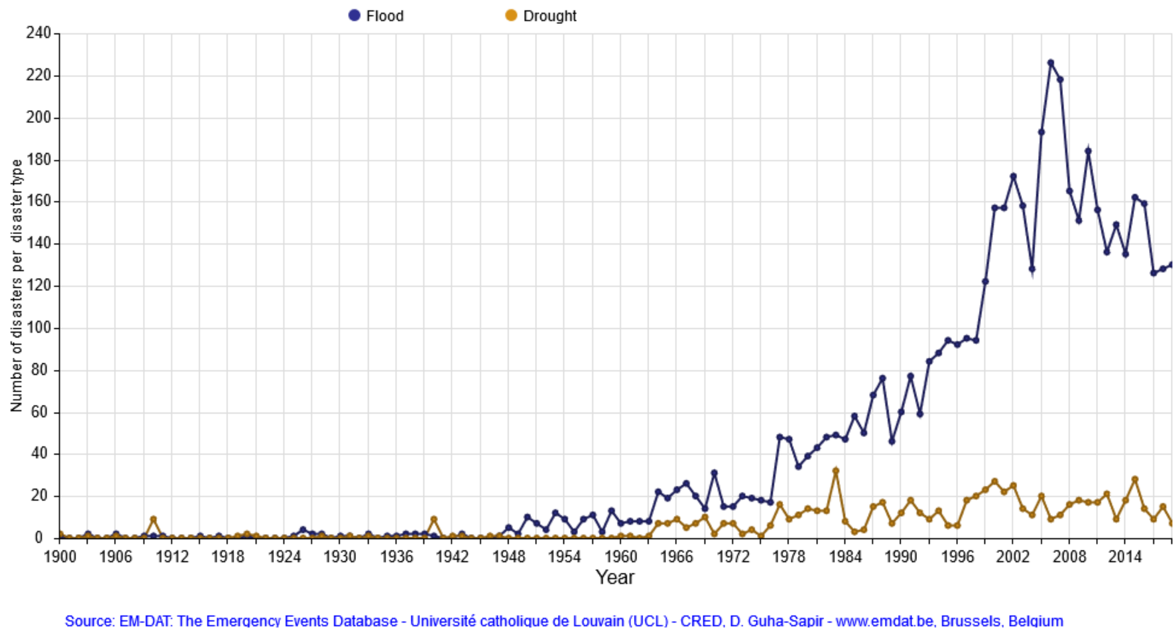

Figure 6: Global trend of flood occurrence (EM-DAT database)

In the Philippines, the recorded drought events by the weather bureau Philippine Atmospheric Geophysical Astronomical Services Administration (PAGASA) were 1987, 1996, 2001, 2002, 2005, 2010 and 2016. Figure 7 shows a drastic decline in the annual rice production on 1987-1988 reporting of the Philippine Statistics Authority (PSA, 2019). In 2010 drought caused by El Niño Southern Oscillation (ENSO) incurred Php2.2 billion in damages to the agricultural sector (estimates from the Provincial Agriculture Office). Furthermore, the impact of the 2016 drought was felt by 43% of the country costing Php5.32 billion worth of damages to the agricultural sector (ACT, 2016). The Department of Agriculture (DA) estimated that 181,687 farmer were affected, and 54% of which are rice farmers, 38% are corn farmers, and the remaining are high value crops. On the other hand, Tongson et al (2017) reported that 68 and 70% in yield losses of maize were simulated using AquaCrop Model when December rainfall was less than 100mm in 1998 and 2010.

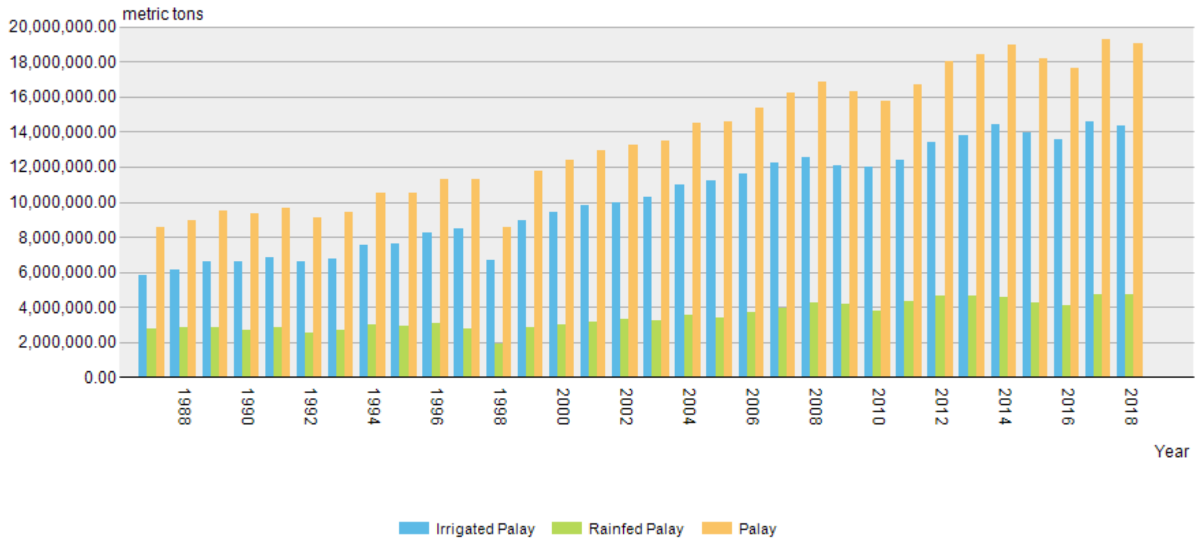

Figure 7: Historical rice production in the Philippines from 1988 to 2019

High-Risk Zones

The climate risk zones was developed using a spatial weighted overlay of five (5) climate related hazards that put pressure on livelihoods and food security (Figure 8.A). Very high climate risk zones in the Philippines are geographically located along the eastern seaboard in Region 2 (Cagayan valley). On the other hand, moderate to high climate risk zones are geographically located along the eastern seaboard of CALABARZON (Region 4A) and Bicol (Region 5) regions. The very high climate risk zones are generally characterized by high risk of the municipality from one to two climate hazards.

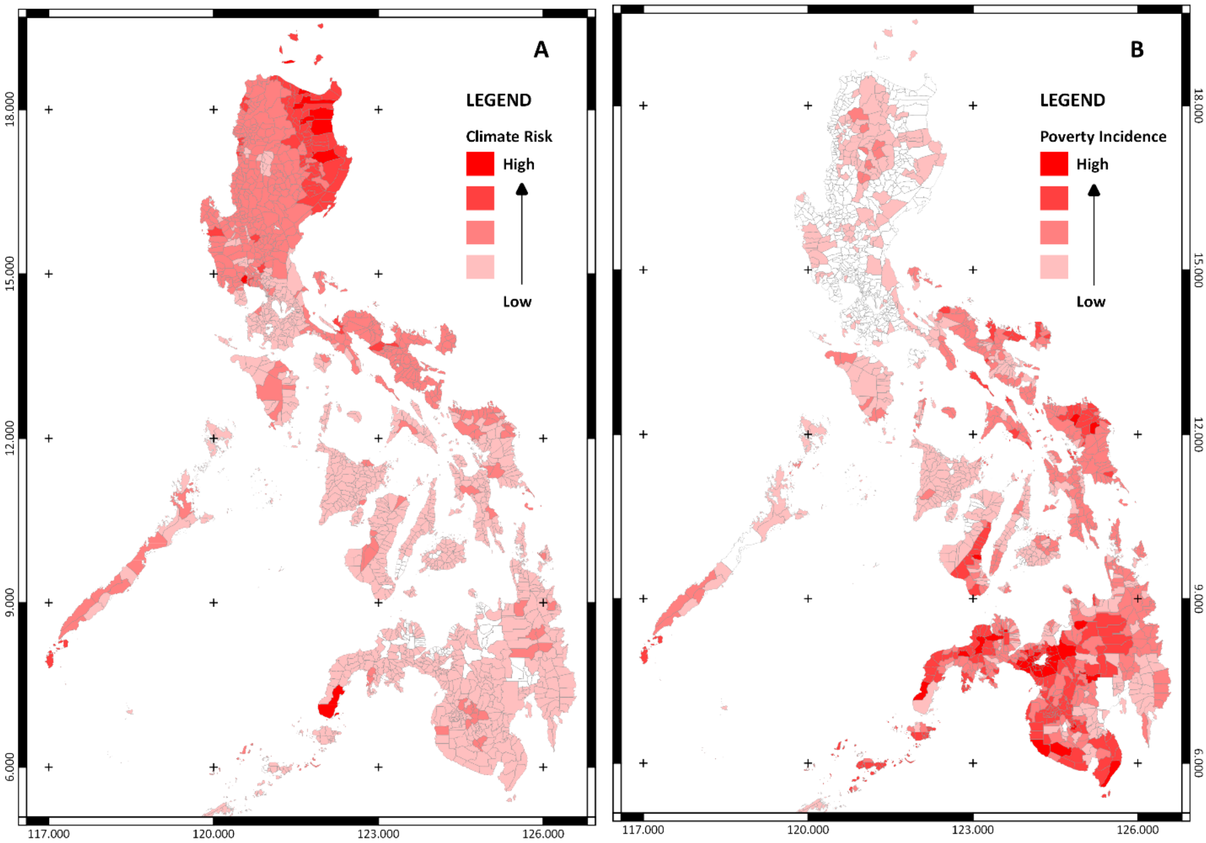

Figure 8: Components for risk zone mapping. A) Climate risk, and B) poverty incidence

For instance, the City of Ilagan in the province of Isabela was classified as very high climate risk zone because of high risk to typhoon, flood, and drought as shows in Figure 9. This was driven by two factors, multiple presence of hazards, and the weights provided for the hazards.

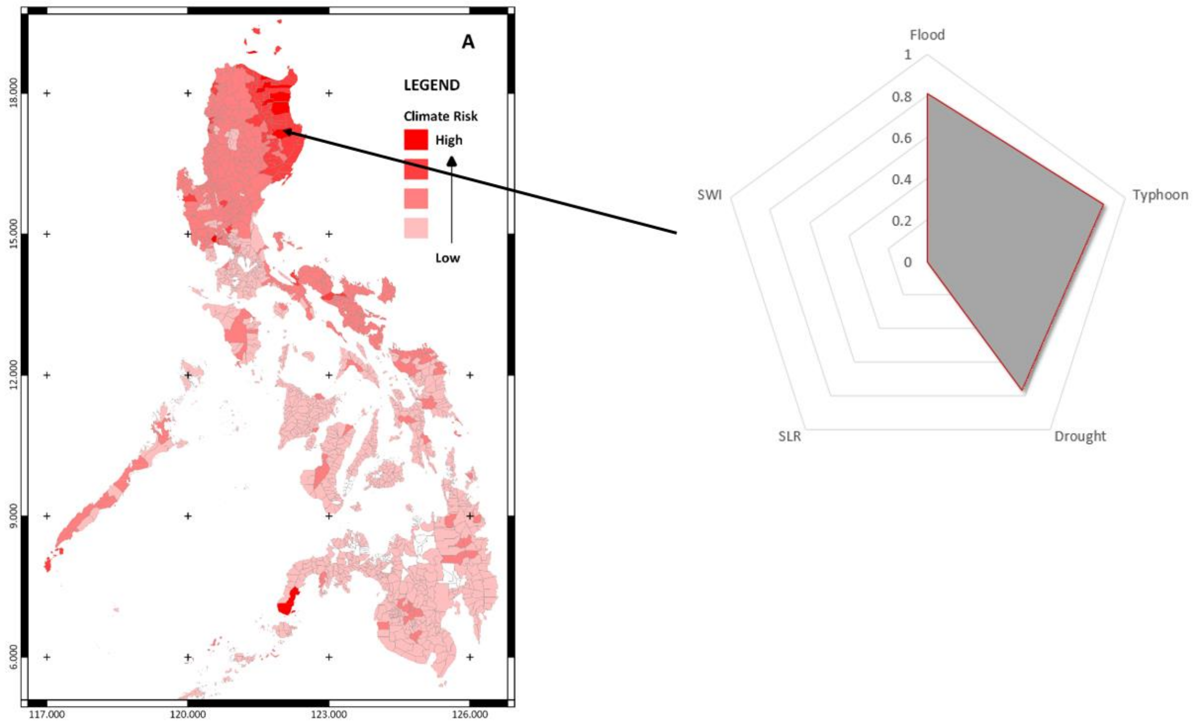

Figure 9: Hazard rating in Ilagan City, Isabela. (SLR = Sea level rise and SWI = Salt Water Intrusion)

On the other hand, high poverty incidence is spatially distributed in Zamboanga, ARMM (Autonomous Region of Muslim Mindanao), SOCCSKSARGEN, and southern part of Davao Region (Figure 8.B). Moreover, high poverty incidence is also observed in the provinces of Northern Samar and Negros Oriental. The high poverty incidence was assumed as proxy to low adaptive capacity. In the concept of vulnerability, adaptive capacity is an important determinant of vulnerability. Municipalities that have both high climate risk and poverty incidence can be classified as high risk zones.

The high risk zones (integration of climate risk and poverty incidence) is shown in Figure 10. There are several conditions for a municipality that can be considered as high to very high risk zone: 1) high poverty incidence – which is a proxy for low adaptive capacity. This means that if they are hit by a climate hazard – even though the municipality has a low climate risk – they will have a hard time coping to the impacts; 2) moderate climate risk and high poverty incidence; and 3) moderate to high climate risk and moderate poverty incidence. Results show that high-risk zones in the Philippines are geographically distributed in the following: northeastern part (Region 2 and portion of Cordillera Autonomous Region), eastern seaboards (Regions 5 and 8), and central to western part of Mindanao (Regions 9, 10, ARMM, and 12).

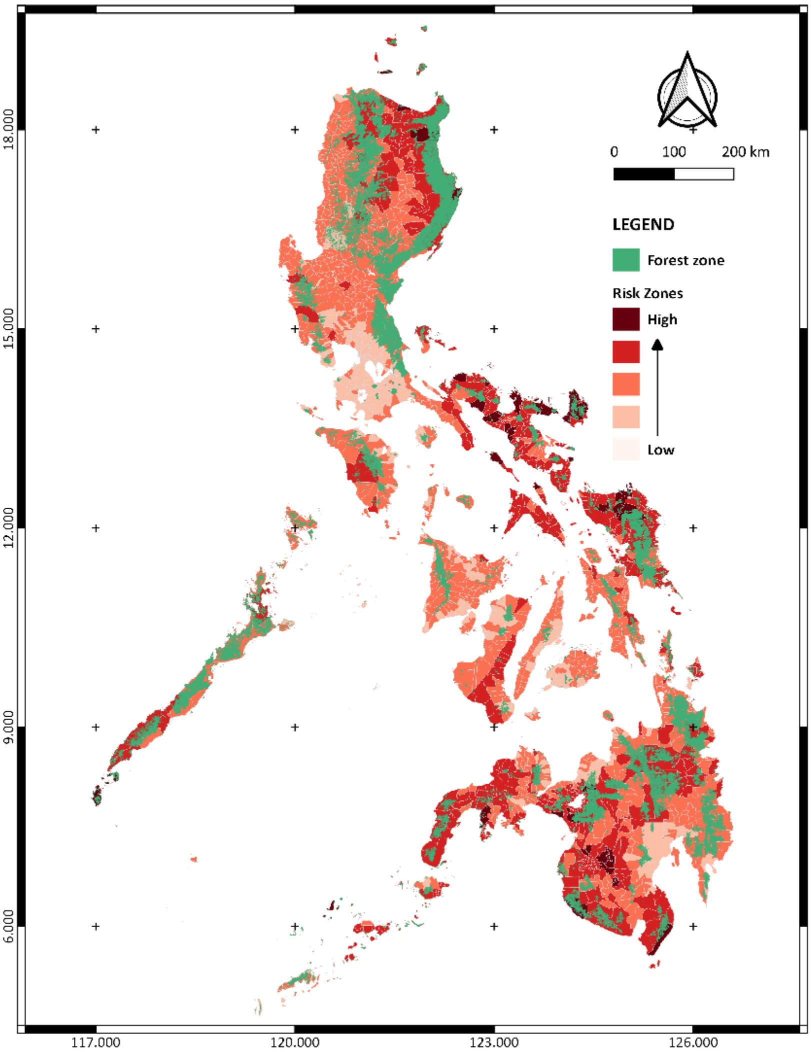

Figure 10: Risk zones based on climate hazards and poverty incidence.

Cluster Analysis of High-Risk Zones

Figure 11 shows the spatial distribution of the municipalities by cluster in the high risk zones. The municipalities classified as high risk zones were based on a risk rating of 0.6 and higher. We produced three distinct groups and each has unique characteristics in terms of hazard risk (e.g. typhoon, flood, drought, salt water intrusion and sea level rise) and poverty incidence.

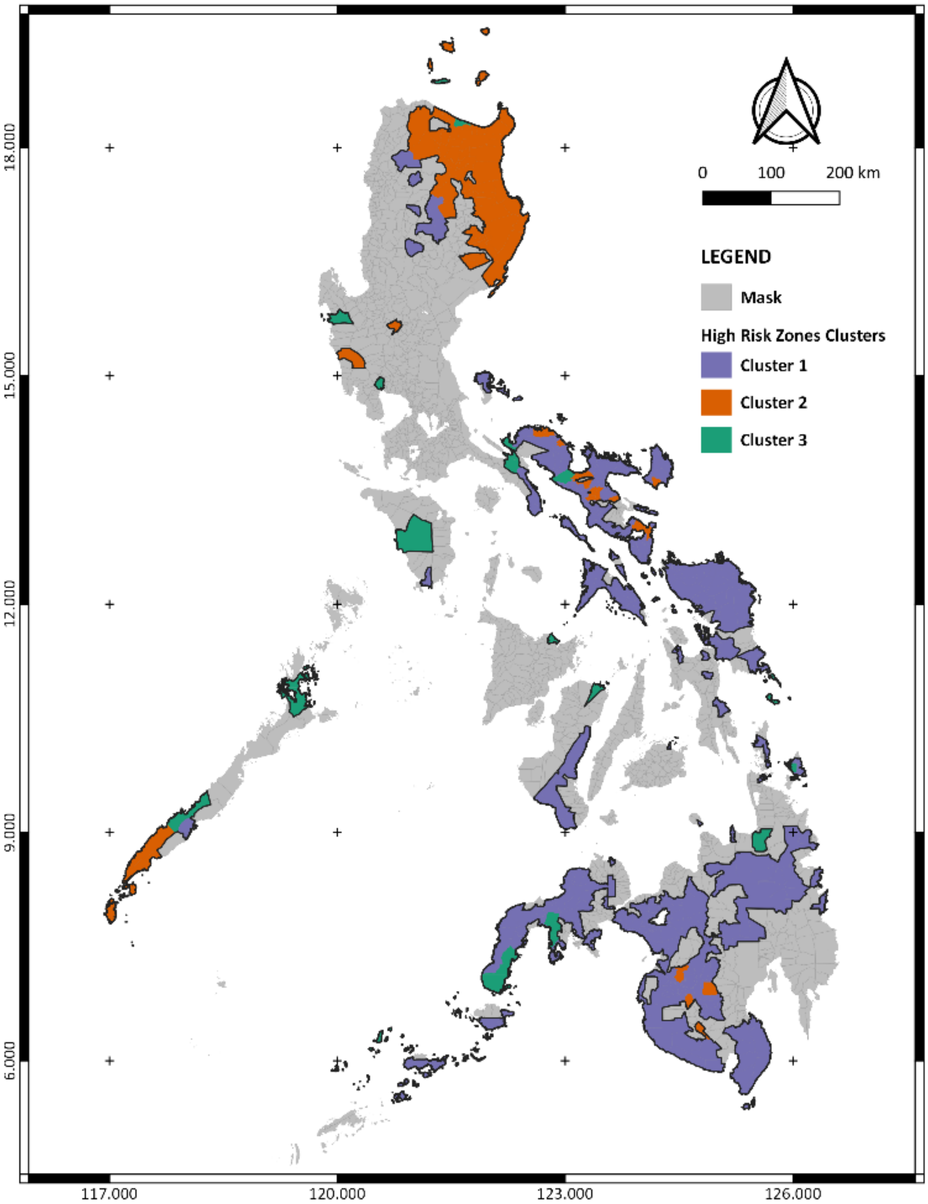

Figure 11: Municipalities grouped according to their risks based on statistical cluster analysis. Municipalities belonging to the same cluster share similar conditions across climate risk ad poverty incidence indicators.

Figure 12 shows the characteristics of each group. Municipalities in cluster 1 show high drought risk. While the risk to typhoon is generally low, there are 43 municipalities (representing ≈10% of the municipalities in cluster 1) – majority is located in Camarines Sur and Norte (22) and Catanduanes (9) – along the eastern seaboard that are at high risk to typhoon. Additional caveat is that poverty incidence is the highest compared to other clusters. The risk for saltwater intrusion and sea level rise are generally low. Also, flood is generally low to moderate, except for the six (6) municipalities in the provinces of Agusan del Sur, Cotabato and Maguindanao that are at high risk to flood. Cluster 2 has the highest risk to typhoon and drought, but poverty incidence is comparatively low as compared to clusters 1 and 3. Majority of the municipalities have low flood risk, except to six (6) municipalities in the provinces of Palawan, Isabela, Cagayan, Cotabato, Sultan Kudarat, and Nueva Ecija. Saltwater intrusion is also comparatively low. Poverty incidence is rated as moderate to low in cluster 3, but it is characterized as being high-risk to drought and moderate risk to flood and sea level rise. Problems on saltwater intrusion is the highest as compared to clusters 1 and 2. Conversely, typhoon is also considered as generally low in this cluster. Here are some of the practical uses for planning climate change adaptation using the result of the cluster analysis.

- **Cluster 1** – agricultural systems should focus on drought resilience. While this is an important consideration in designing the package of agricultural interventions, it should also not neglect addressing other climate risks, such as typhoon and flood (in some municipalities). Since it also has the highest poverty incidence, the intervention should develop agricultural value chains that focus on reducing poverty and more participation of smallholder farmers.
- **Cluster 2** – agricultural systems should focus on addressing the typhoon risk. Adaptive cropping calendar by changing the cropping pattern to mitigate the effect of typhoons during wet season should be considered. Moreover, drought resilient farming systems and provision for drought resistant crop varieties should be incorporated in the package of interventions.
- **Cluster 3** – agricultural intervention should focus on provision for drought resilience cropping system. Flood resilient should also be considered in this cluster. Provision for salt tolerant varieties/crops or adaptive cropping calendar that minimizes the exposure to salt water intrusion during the dry season in coastal areas can be considered.

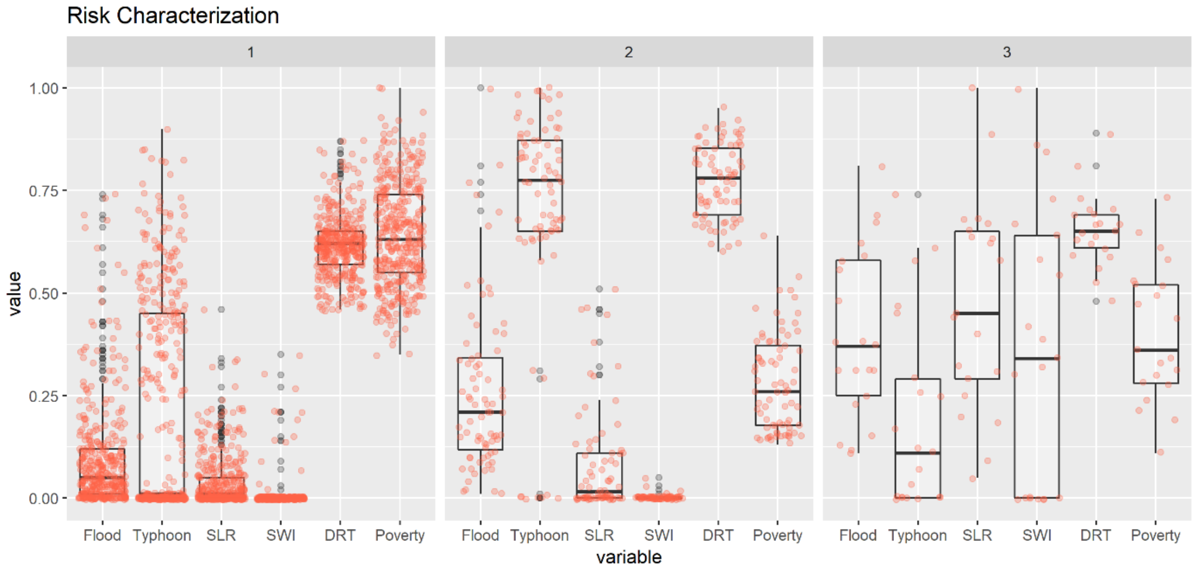

Figure 12: Characterization of risks by cluster

Relevance of RTB in the High Risk Zones

Figure 13 shows the climatic suitability of sweet potato, cassava, and potato in the high risk zones based on the result of the simulation across Asia (FoodSTART+, 2019). Using RCP8.5 scenario, the sweet potato and cassava remains highly suitable by year 2050; such that it is classified as suitable to excellent conditions in majority of the areas in the high risk zones. On the other hand, potato is simulated to decrease in climatic suitability and will likely recede to higher altitudes due to warmer temperature. Aside from its resilience to climate change, sweet potato and cassava are known to tolerate drought (or drier than normal) conditions which is a risk in all clusters, especially in cluster 2. Moreover, these crops can also endure typhoons as compared to rice and maize which is a promising option for municipalities in cluster 2. During post-Haiyan assessment, it was shown that RTBs, especially sweet potato survived the devastation and was used by the communities to mitigate food scarcity (CIP 2019). This only shows that growing importance of RTBs in high risk zones, not just in the Philippines but in other regions as well.

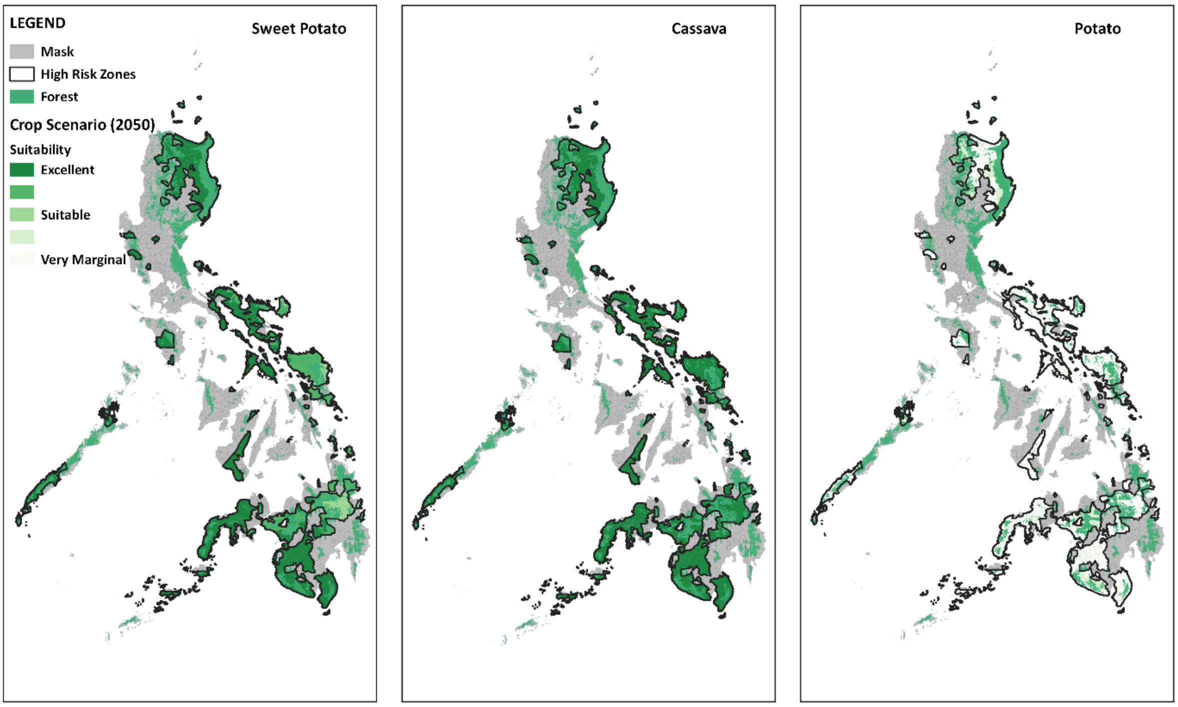

Figure 13: Relevance of root and tuber crops (sweet potato, cassava, and potato) in the high risk zones in the Philippines

Conclusion

The high-risk zones to climate change, variability and extremes was assessed and mapped in all municipalities in the Philippines using spatial modeling and statistical analysis of climate hazards and poverty incidence. The analyses focused on key climate risk that threatens the productivity of agricultural commodities in the Philippines. The municipal resolution was used because the authors believed this is where significant decision making and planning takes place, especially in the agricultural sector.

The mapping of high risk zones can be used to inform and guide decision makers from government agencies and private sectors on geographic areas that are in most need of interventions, and the package of interventions needed for each geographical area. It also opens door for cross-sectoral collaboration between different government agencies and private sectors. The result of the study will directly contribute to the on-going initiative of the Philippine government to reduce climate risk and improve livelihoods of the agricultural sector thru the provision of climate smart agriculture. Any options of agricultural interventions for climate change adaptation should undergo a cost and benefit analysis to ensure that it is profitable and economically viable to farmers and other stakeholders, especially smallholders. With inherent uncertainties of the analysis and modelling outputs, any planning and development initiative using the output of this research should be made with consideration of local conditions or with consultations with local authorities.

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